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NATIONAL BUREAU OF STANDARDS

Technical News

BULLETIN

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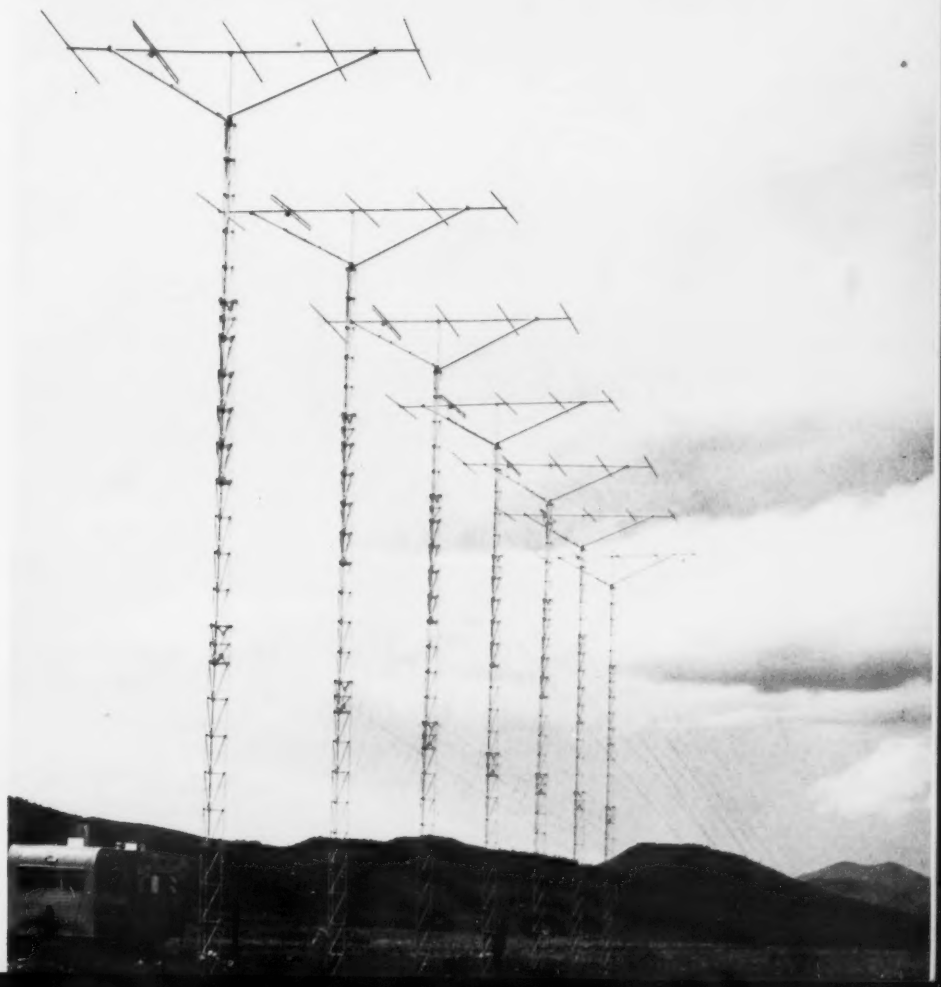
1960 Conference on Standards and Electronic Measurements



U.S. DEPARTMENT OF COMMERCE FREDERICK H. MUELLER, *Secretary*

NATIONAL BUREAU OF STANDARDS A. V. ASTIN, *Director*

NATIONAL BUREAU OF STANDARDS

Technical News

BULLETIN

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Contents

	Page
1960 Conference on Standards and Electronic Measurements	145
High-Resolution Scanning Antenna	155
Mobile Electronic Laboratory	156
Announcing the Third National Symposium on Temperature—Its Measurement and Control in Science and Industry	156
U.S.-Japanese Intercomparisons of Microwave Power Standards	157
Adjustable Waveguide Termination	158
A Proposed Analog-Digital Differential Analyzer	159
Publications of the National Bureau of Standards	160

COVER: Seven 5-element Yagi antennas erected at the Bureau's Table Mesa (Colorado) field site. The antennas, in conjunction with an electronic scanning device, are used to pinpoint the direction of radio signals received from "forward scatter" transmission. The equipment can also be adapted for observation of a number of other ionospheric phenomena. (See article on p. 155.)

1960 Conference on Standards and Electronic Measurements

MORE than 800 scientists and engineers from industry, universities, and Government participated in a Conference on Standards and Electronic Measurements, held June 22 to 24, at the Bureau's Boulder (Colo.) Laboratories. Sponsored by the American Institute of Electrical Engineers, the Institute of Radio Engineers, and the National Bureau of Standards, the 3-day meeting provided an opportunity for the exchange of information and ideas concerning the most recent developments in the field of electronics and measurements.

The technical program, under the chairmanship of Dr. George E. Schafer (NBS-Boulder), presented 40 papers during 6 technical sessions. These included *Current and Future Problems in Standards and Electronic Measurements; Frequency and Time Standards; Methods of Measurement for Materials; Microwave Standards and Calibrations; Direct Current and Low-Frequency Standards and Calibrations;* and *High-Frequency Standards and Calibrations.* Among the more important and interesting topics covered were standards and measurement techniques for electrical quantities at frequencies ranging from direct current through the microwave region, the most pressing current problems in establishing universally accepted consistent standards, and a considered speculative look at the most probable causes of difficulty in the future in making standards and electronic measurements.

Advances in the field of standards and measurements since the first such conference in Boulder in August 1958 have served to emphasize the need for constant effort to improve accuracy in electronic measurements and standards. In addition to the continuing problems in large-scale precision production of electronic equipment, instruments, and systems—including major parts of aircraft control, rocketry, and missile guidance—the advent of space vehicles has brought to the fore the need for highly specialized electronic systems whether the vehicle be manned or unmanned. For satisfactory operation, the separate components of these different systems must be chosen particularly for their function and constructed and evaluated according to accurate reference standards. Very slight deviations from electronic specifications may result in complete failure of a missile or other device.

In the past 2 years, tremendous strides have been made in developing and applying industry-wide standards, but the electronic industry keeps expanding so rapidly that it has been impossible for research in electronic standards to keep pace. Furthermore, interchange of information has lagged behind the acquisition of such information, with resulting differences between reference standards developed by one organization and those of another. Uncertainties and variations in electric standards and radio materials have resulted in electronic units being built and used without precise knowledge as to how well they will operate or how long they will last.

The critical importance of common standards, adopted by all, was emphasized by the technical sessions of the Conference. Large attendance, lengthy private discussions, and the exchange of questions and answers between platform and floor made it clear that both industry and government are aware of the urgent need for universally accepted, consistent measurement standards in the electronic field on a still more advanced level than ever before.

Dr. Frederick W. Brown, Director of the Boulder Laboratories, opened the conference. He was introduced by Conference Chairman Ivan G. Easton (General Radio Co.). In his opening address, Dr. Brown discussed the importance of standards and measurement techniques to electronics and emphasized the need for a systematic approach to the wide range of standards and measurements problems associated with the field.

The participants also heard a talk by Dr. Bernard M. Oliver (Hewlett-Packard Co.) at the Conference luncheon on June 23. Dr. Oliver reviewed the role of quantitative measurement in

The Proceedings of the Conference will be published by the IRE Professional Group on Instrumentation about November.

the development of the sciences. He stressed the importance of precise measurement in exploring second-order effects that might not be revealed by less precise experimentation, and the cooperation of science and technology to provide the precision instruments needed for further research. He also pointed out that in many cases science can be overprecise, resulting in unnecessary complexity and expense where less precision could still provide adequate performance of equipment.

Session I: Current and Future Problems in Standards and Electronic Measurements

During the first session of the Conference, presided over by L. B. Wilson (Sperry Gyroscope Co.), some of the more pressing needs for increased accuracies, greater ranges, and new categories of measurement in the field of electronic standards were examined. These needs were roughly defined by several calibration surveys, the most prominent being that of the Aerospace Industries Association in connection with the design and development of advanced military weapon systems.

Col. R. F. Stolle (Wright-Patterson AFB) presented an orderly approach to determining the precision measurement requirements of an aerospace system through research and development. Particular emphasis was given to the steps needed to maintain integrity of measurement requirements in the production and operational phases by using proper calibration equipment and methods. The suggested approach was also extended to a hypothetical space research system.

J. B. Herbert (Goddard Space Flight Center) discussed the system and component requirements of a satellite-tracking system having an accuracy of 0.1 milliradian under optimum conditions. The radio-interferometer angular-tracking system, Minitrack, makes extensive use of techniques which minimize the effects of component inaccuracies, yet some precision components are needed. The time standard, in particular, was designed to have an accuracy of 1 part in 10^8 or 1 msec/day. The results of 2½ yr of tracking experience were given and reference made to the extensive geophysical data acquired.

W. G. Donaldson (Federal Electric Corp.) spoke of the many problems encountered when a complex radar and communications system such as the DEW line must be kept within specified tolerances during operation. Lacking an integrated calibration system, a standards laboratory and mobile calibration team had to do the job with more than 80 different types of test equipment. Although the standards in use were certified by NBS and the National Research Council of Canada, there were also problems of establishing valid calibration procedures.

H. W. Lance (NBS-Boulder), Chief of the Electronic Calibration Center, undertook an examination of the concept of "traceability of calibrations to NBS" and the conditions under which this traceability may be said to exist, as part of the larger problem of increasing demand for calibration service from NBS in the effort to achieve nationwide standardization of electronic measurements. Particular attention was directed to criteria for staff and instrumentation of electronic standards laboratories, the choice of interlaboratory standards to be submitted to NBS, and the use of these standards before and after calibration. Services available and what to do when needed calibration services are not available from NBS were outlined.

A. G. McNish (NBS-Washington) attacked the prevalent fallacy that in a chain of standards traceable back to a central laboratory each standard must be calibrated in terms of a standard 10 times more accurate. The converse implies a tenfold degradation in accuracy with intolerable conditions at the working level. Experimental data on errors in calibrations and an examination of factors affecting accuracy in calibration indicated that a more realistic—and accurate—view is that a chain of standards is as accurate as its weakest link.

Dr. E. L. Crow (NBS-Boulder) presented a statistical mathematical approach to the problems of accumulated error in a hierarchy of calibration. Referring again to the frequently made statement that the accuracy of each echelon should be 10 times the accuracy of the immediately following echelon, he derived formulas for the total error accumulated over the entire sequence when systematic and random errors may occur at each echelon, and for determining how a given total error may be achieved at minimum total cost under reasonable assumptions for the form of the cost-error functions.

E. Peebles (Lockheed Aircraft Corp.) commented on an extension of normal industrial operation undreamed of in the past: maintenance of an adequate chain of calibration in the complex of subcontractors and vendors involved in a prime defense contract. Since standards with constantly narrowing interrelating tolerances must be supplied, the prime contractor is obliged to coordinate the calibration programs of his suppliers to assure compatibility, and to see the proper ratios of accuracy between each level of calibration, adequate frequency of calibration, and direct traceability to the national standards are maintained.

On the evening of June 23, informal evening discussions, including papers, were held, supplementing the work of three regular technical sessions. Part I of the evening discussions related to the work of Session I. It was moderated by Herbert Barnhart (General Electric Co.-Syracuse, N.Y.) and dealt with *Traceability*, *Stability*,

and Compatibility of Measurements and Calibrations.

During these discussions, F. M. DEFANDORF and F. L. HERMACH (NBS-Washington) presented an analysis of errors in tests of electrical instruments which gave further evidence that in some cases a much smaller ratio than 1 to 10 can suffice for the relation between the accuracy of a standard and that of the instrument being calibrated.

R. E. MCCALLUM (Sandia Corp.) reported on 5 years of experience in making annual intercomparisons of reference standards for several of the electrical units, principally of EMF and resistance, at Los Alamos Scientific Laboratory, White Sands Missile Range, and Sandia Corp. Evaluation was made of the limits on accuracy imposed by intercomparison equipment, procedures, and conditions.

L. H. BRESSAN (Sandia Corp.) presented the results of a study of long-term stability of standard resistors and precision potentiometers, with accessory volt boxes and shunts, used in the standards program for the AEC Atomic Weapons System. He concluded that intervals between certifications could be extended from 1 to 2 years, provided that certification was supplemented with

Excerpts—CONFERENCE KEYNOTE ADDRESS

Frederick W. Brown, Director, NBS Boulder Laboratories

The National Bureau of Standards must provide National leadership in the development and use of accurate and uniform techniques of physical measurements in all fields, including electronics; and must provide the central basis within the United States of a complete system of physical measurements, coordinated with measurement systems of other nations. We must provide essential services leading to accurate and uniform measurements and provide data on the properties of matter and materials which are of importance in science and technology, and are not elsewhere available.

The Bureau is not in a position today to furnish adequate standards in the field of electronics and in many other fields. One of the major functions of this conference is to point out where gaps exist, what is being done, and what must be done in the future. The NBS staff is trying very hard to keep up with the rapidly expanding requirements of scientists and engineers in the field of electronics. We sometimes become a little discouraged by the tremendous job to be done and the rather limited resources available to do it. But conferences such as this should certainly help us all in planning how best to approach the problems.

Obviously, this does not mean that the Bureau must develop all National reference standards and standards measurement techniques itself, but it must be in a position to insure that such standards and measurement techniques exist, are of sufficient accuracy for the needs and potential needs of this country, and are available to all potential users in the Nation's scientific and technologic community.

A basic requirement for useful standards is that they must be consistent within the whole chain of measurement leading back to the international prototype standards representing the fundamental units of length, mass, and time. A specific laboratory may at times develop instruments able to provide precisions greater than can be furnished by the central standardizing laboratories, but they do not have general applicability and consistency until brought in line with the whole measurement complex.

Today, there is a trend to break away from the old prototype standards and to base all measurement standards on natural physical constants. Eventually, specified atomic constants may be used as the measurement basis for length and time. These constants afford obvious advantages such as increased accuracy and stability, free availability to all laboratories, and less dependence on elaborate centralized calibrations based on prototype standards.

In this country, we depend on close cooperation between NBS and industry to insure the availability of accurate standards. This places special responsibilities upon all of us. A great many things are already being done to increase the effectiveness of this cooperation, but much still remains to be accomplished.

In Russia, however, all standardization is under rigid centralized control. Precision can be enforced by edict on a central basis and is given a great deal of attention with 5 major R&D establishments on measurements and instrumentation and about 100 calibration centers. In the final analysis, our system can have greater strength because it gives free play to individual creativity and ingenuity—sources of new ideas. Centralizing may ease administration and enforcement, but it always tends to inhibit creativity.

We are all faced with a very major problem in keeping up with the explosively increasing demand for accurate and uniform standards and measurement techniques. This requires very close cooperation of all interested parties, and conferences such as this should be very fruitful in helping us meet our mutual responsibilities.

semiannual cross-checks and rigorous visual inspection.

L. E. Hachey (Avco R.A.D.) discussed the dependence of calibration on procedures. He pointed out that successful performance evaluation of space-age equipment depends largely upon a universally accepted calibration ability which, in turn, uses procedures as a medium of universal communication between laboratories, an aid in training, and an outline of necessary equipment and environment for a qualified calibration facility.

J. A. Orme (Aerojet-General Corp.) presented an integrated operational plan for an industrial standards program with a chain of calibrations extending from workbench instruments to national reference standards. Realistic selection of equipment, adequate proveout, and installation provisions were emphasized.

M. C. Selby (NBS-Boulder) discussed two proposed programs for national and international standardization of electronic quantities. Product of more than 2 years of preliminary work, these programs are concerned with electronic quantities at all frequencies. They deal with ranges of magnitude, respective accuracies, needs, available values, and calibration echelons. Major objectives and anticipated benefits from their probable inauguration in the near future were outlined.

Excerpts—CONFERENCE LUNCHEON ADDRESS

Bernard M. Oliver, Hewlett-Packard Co.

Science is essentially the discovery of natural laws and relationships. The functional form of these can only be proven by experiment, and the crucial experiment is often one of great delicacy . . . .

Up to the present century, science has been concerned for the most part with what might be called first order effects. With notable exceptions, great precision in measurement was unnecessary.

The laws of motion, the laws of gases, the Mendelian laws of heredity, the laws of stoichometric ratio which established the existence of the atom and converted alchemy to chemistry, the laws of electricity and magnetism, were all established by experiments of only moderate precision.

In fact, it is probably fortunate that many earlier experiments were not more precise—for then a host of second order effects would have obscured the picture and slowed down the rapid advances made by early investigators. The basic laws might have been held in doubt much longer.

Today the picture is very different: when precise measurements uncover a slight discrepancy in some experiment we seize on the discrepancy as evidence of some hitherto unexpected weak coupling or unknown perturbation which might lead the way to greater knowledge. Indeed, much of the progress of science in the last decades has been due to the relentless tracking down and explaining of slight discrepancies revealed by precise measurements . . . .

Only 43 seconds of arc per century—an almost negligible but definitely present effect—was totally unexplained by Newtonian mechanics.

It was the ant at science's picnic!

Einstein's general theory of relativity showed Newton's law of gravitation to be only a first order approximation and predicted that Mercury's orbit should indeed precess by 42.9 seconds of an arc per century. Today, even with the Mössbauer effect, this remains the only evidence in support of the complete general theory . . . . In spite of all temptation over the years, nobody fudged the data; nobody stepped on the ant . . . .

There often arises in engineering a situation where better performances in one part of a system can actually worsen the overall result . . . an example is a radar which may contain in addition to random noise certain systematic errors . . . By reducing dispersion due to noise to much less than the systematic errors, the performance becomes very bad.

It is really this matter of balance between random and systematic error that is one clue to whether precision is being used or abused for instrumental error tends to be systematic.

Now one often hears the argument: What's the harm? Maybe we didn't gain anything—but at least we didn't lose anything with the more accurate instrument . . . . I think that the answer is that a great deal is often lost with overprecise instrumentation—it is far more costly, often resulting in a waste of money—and, secondly, more accurate instrumentation is in general more complex. Complexity, in turn, implies unreliability . . . .

Let us keep on making more and better high precision instrumentation, but let us use it where its accuracy is truly needed. Let's not use our cannon to kill moths, or—as Mr. McNish puts it—"use micrometers to measure two by fours."

I suggest that our progress will be surer and more rapid if we use good judgment; make measurements only to accuracy really required, and use the simplest, most rugged instruments to do it.

Part II, moderated by L. B. Wilson (Sperry Gyroscope Co.), dealt with *Calibration Laboratory Policies, Organization and Operation.*

C. E. White (Avco R.A.D.) stressed the importance of enlightened management. He described it as either contributing to or weakening a standards operation in proportion to the education it receives in standards. At the same time, standards must earn and retain prestige within the industrial establishment.

A. S. Moore (General Electric Co.-Syracuse, N.Y.) described the quality control electronic test equipment calibration program at General Electric Heavy Military Electronic Department, Syracuse, N.Y. This equipment is used in testing and measuring the performance of research, development, and production types of equipment. Facilities include three calibration laboratories, strategically located to provide services to each of three major plants with a minimum of lost time.

H. Liiv (General Electric Co.-Utica, N.Y.) outlined the calibration system in operation in the Light Military Electronics Department of his company. Through automatic data processing, the quality, reliability, and efficiency of calibration and maintenance work are constantly measured and corrective action taken immediately. An analysis and control group handles establishment of calibration frequency, discarding inferior equipment and adjusting facilities and techniques.

A. J. Woodington (Convair Astronautics) pointed up a problem in the use of standards laboratories by industry: the requirement of a high degree of reliability and accuracy in terms of both people and equipment in military and industrial systems of the future. The shortage of qualified people might be overcome, he suggested, by having the standards laboratory use its personnel to provide technical assistance and on-the-job training for members of other engineering groups. The amount and cost of equipment can be kept to a minimum by assigning responsibility for standardization and use to the standards laboratory itself.

Session II: Frequency and Time Standards

Roger A. Sykes (Bell Telephone Laboratories North Andover, Mass.) presided over the second session which was introduced by a status report on frequency and time signals presented by F. G. Merrill (Bell Telephone Laboratories Murray Hill, N.J.). This report outlined the differences and difficulties encountered in maintaining frequency standards by atomic beam devices, alkali vapor frequency standards, crystal oscillators of special design and with transistor circuitry, and synchronization of time and frequency over great distances.

R. C. Mockler (NBS-Boulder), Chief of the Atomic Frequency and Time Standards Section of the Radio Standards Division, presented a paper, written in collaboration with R. Beehler and L. Fey, on atomic beam devices, particularly the two NBS cesium frequency standards. Various uncertainties in frequency measurements were discussed, including the effect of the uniform "C" field, the effect of a phase difference between the two oscillating fields that excite the atomic transition, and the effect of exciting an atomic transition with signals that are not monochromatic. Tests for determining the uncertainties in frequency measurements in cesium beam devices, and the results of such tests, were also given.

R. J. Carpenter, E. C. Beaty, P. L. Bender, S. Saito, and R. O. Stone (NBS-Washington) offered the results of work on a prototype rubidium vapor frequency standard undertaken in cooperation with the Radio Techniques Branch of the Naval Research Laboratory and currently supported by the National Aeronautics and Space Administration. Research on an alkali vapor frequency standard during the past 2 years has been carried on with the aim of developing such a standard for possible use in a satellite-borne measurement of the gravitational frequency shift predicted in Einstein's General Law of Relativity. Relative frequencies of several rubidium vapor absorption cells have been shown to remain stable for 1 part in 10^{11} or better for a period of one month.

T. C. Anderson and F. G. Merrill (Bell Telephone Laboratories-Murray Hill, N.J.) reported on solutions of frequency-stability problems in 2.5- and 5-Mc quartz oscillators using the modified Pierce-oscillator circuit, employing the new AT-cut contoured crystal unit. Thoroughly analyzed, and tested under rigorous conditions, this circuit has gained widespread use since its introduction about 7 years ago. However, the deceptive simplicity of the circuit hides numerous problems encountered in designing a suitable production unit. A balanced design to achieve fractional part-per-billion frequency stability, using precise commercial components, must take into account all reactance variations, crystal-current stability, tube and component aging margins, and rugged environmental conditions to achieve this result at high frequencies.

W. L. Smith (Bell Telephone Laboratories-Whippany, N.J.) presented the results of work on crystal-controlled transistor oscillator circuits employing precision AT-cut quartz resonators. These transistor oscillators provide short-term frequency stability comparable to vacuum-tube frequency-standard oscillators and are considerably reduced in size and power drain. Different types, suitable for fixed-station applications, capable of operating in widely varying ambient conditions, and others designed for very low

power drain and capable of withstanding the extreme mechanical environments of missiles and satellite-borne applications, were discussed. Performance tests were shown for operation during quiet conditions and during vibration, shock, and static acceleration.

J. A. Barnes and R. C. Mockler (NBS-Boulder) described the power spectral density functions of crystal oscillators and multiplier chains. The frequency of an ammonia maser stabilized chain was demonstrated to be relatively fixed. An analysis was made which related the instantaneous frequency fluctuations of a signal with the power spectral density function. Experimental observations in agreement with this result were discussed. If signals having a complex power spectrum are used in precise measurements, it was pointed out, errors may result.

R. R. Stone, Jr. (Naval Research Laboratory-Washington, D.C.), W. Markowitz, and R. G. Hall (U.S. Naval Observatory) described the various kinds of time as determined by the Naval Observatory and a system of atomic time known as A.1. Absolute frequency is based on ephemeris time, ET; the observed and adopted value for the specified cesium line (A.1) being 9,192,631,770 cps. The stations in the United States and the United Kingdom which distribute the frequency and time standards were described. A detailed story was presented on the Navy's VLF station, NBA services broadcast, and some techniques of their use.

The night session on *Frequency and Time Standards*, moderated by Roger A. Sykes, had no formal papers but discussion covered the following topics:

What is the maximum stability and spectral purity now available from laboratory-type oscillators—(*a*) quartz, (*b*) maser, (*c*) beam, and (*d*) gas cell? What are the problems with such oscillators and resonators in a standards and measurement laboratory? Are there outstandingly preferred methods for the precision measurement of (*a*) frequency, (*b*) time interval? What are the problems in reception and use of standard frequency transmissions and time signals (*a*) on earth, (*b*) with regard to missiles and satellites? Are there needs in technology and science for improved standards and measurements for frequency and time? Should we discontinue referring to frequency bands by adjectives such as VHF, SHF, etc., and instead use band-numbers?

Session III: Methods of Measurements for Materials

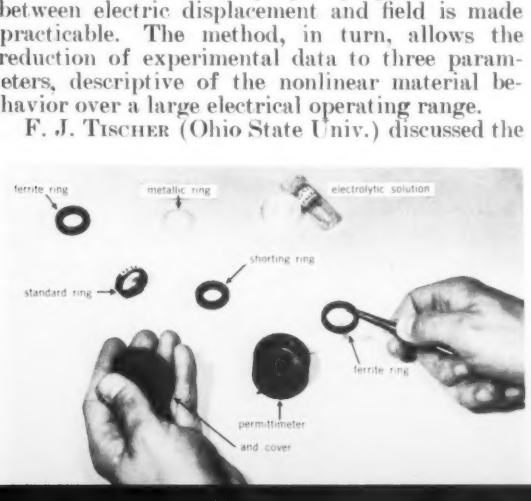
The session on Methods of Measurements for Materials was under the chairmanship of John L. Dalke, Chief of the Radio and Microwave Materials Section (NBS-Boulder). Mr. Dalke opened the session with remarks on the increasing need for information and techniques on measurement of materials at radio and microwave frequencies. Dielectric, semiconductor, and magnetic materials are finding wide applications in science and technology.

P. N. Wolfe (Westinghouse Research Laboratories) described a new technique for analyzing experimental data on the behavior of devices employing low-dissipation-factor ferroelectric ceramics as nonlinear dielectrics. By observing certain experimental precautions, as in preparing standard samples, and following specific methods, a method of numerically specifying the relation between electric displacement and field is made practicable. The method, in turn, allows the reduction of experimental data to three parameters, descriptive of the nonlinear material behavior over a large electrical operating range.

F. J. Tischer (Ohio State Univ.) discussed the basic measurement of three characteristics of plasma in the test section of a waveguide in a microwave circuit. Electron density, plasma frequency, and collision frequency can be determined by measuring the phase shift and attenuation introduced in the presence of the plasma, and rigorous equations can be derived for evaluating the measured values of these parameters.

H. E. Bussey (NBS-Boulder) reported the results of experiments measuring microwave skin depth conductivity, surface impedance, and Q. It appears that the metal walls of a cavity resonator become standards of skin depth when the internal Q is determined if the walls are uniform and if contact loss is eliminated as in the circular TE_{011} mode. By replacing an end plate standardized in this way with another flat piece of material, it is easy to determine the unknown's skin depth. As to Q, a copper cavity in use displays 94 percent of theoretical Q, reaching 97 percent when deoxidized. It is believed that surface roughness and mode conversion account for the remaining error in Q.

J. R. Seifert and G. L. Allerton (Western Electric Co.-Allentown, Pa.) developed a new approach to the measurement of volume resistivity of semiconductor material at X-band frequencies. This measurement is usually made by sending a direct current through a sample of the material and measuring the voltage drop across two points



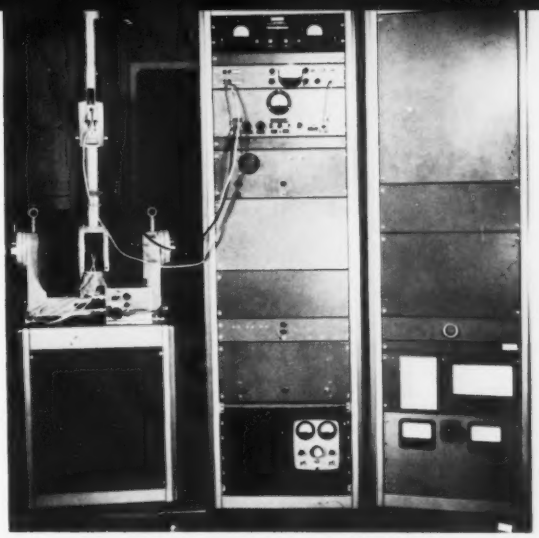
A radiofrequency permittimeter is shown with standard ring, shorting ring, and rings of materials to be measured.

on the surface of the material. The proposed advance consists of conducting this measurement with a high frequency test signal and using test samples to load the transmission system to determine the resistivity of limited areas and depths of material.

R. C. Powell and A. L. Rasmussen (NBS-Boulder) reported on a radiofrequency permittimeter, a new instrument, that shows complex conductivities differing considerably from those previously observed by other methods for ferrites and strong electrolytic solutions. The design embodies a coaxial radiofrequency impedance transformer in which the secondary is a single turn of the material to be measured. This instrument is used with two terminal impedance bridges to determine the complex permittivity or complex conductivity of low-impedance materials. As no electrodes are needed, many conductors, semiconductors, electrolytes,and high permittivity materials can be evaluated to about 1 percent. Errors due to electrode impedance and interaction, as well as first order series inductance, are eliminated.

T. Kohane (Raytheon Co.) presented a cavity perturbation method for measuring the resistivity at microwave frequencies of small spherical polycrystalline samples. The sample is placed in the cavity at a region of maximum magnetic fields. The eddy current losses induced in the sample can be measured to determine the sample resistivity. No assumption is made regarding the depth of penetration of fields, as the influence of skin effect is accounted for. Measurements were made both above and below room temperatures.

J. F. Ollom and W. H. von Aulock (Bell Telephone Laboratories-Whippany, N.J.) discussed specialized techniques for measuring microwave ferrites at high signal levels. The instrumentation included suitable waveguide configurations and equipment for measurements at peak power levels up to several hundred kilowatts. The advantages and limitations of small and large ferrite samples were stated. Experimental results were given concerning the determination of the critical internal RF magnet field (h_{crit}) at which the loss characteristics of the ferrite become nonlinear;



Vibrating sample magnetometer developed at the Bureau. Assembly at left contains field magnets on opposite sides of the vibrating rod system (shaft, center). The vibrating sample is between the pole pieces of the magnets. Controls and measuring instruments are at right.

measurement of the loss characteristic as a function of the biasing d-c magnetic field at a given RF signal level; observation of deterioration of the transmitted pulse; and measurement of high power effects as a function of material composition sample and shape and size.

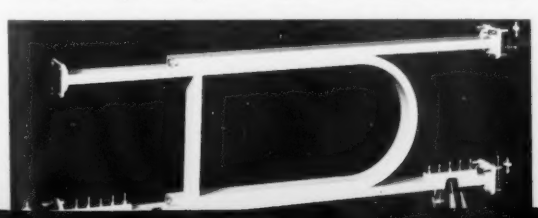
N. V. Frederick (NBS-Boulder) presented an advance in magnetic measurement technique: a vibrating sample magnetometer that makes any modification of the magnet employed unnecessary and provides a self-calibrating system. The sample is mounted at the end of a glass rod which is mounted in the plane of the magnet gap. The rod is vibrated in its gravest flexural mode. The vibration frequency and amplitude are controlled by feedback circuitry. The sample is vibrated parallel to the magnetic field and normal to the plane of the pickup coils which are mounted upon the magnet pole pieces. The voltage induced in the pickup coils is measured by a feedback amplifier voltmeter which allows an absolute accuracy of 1 percent or better.

Session IV: Microwave Standards and Calibrations

Milton Magid (FXR, Inc.) was chairman of the fourth session, *Microwave Standards and Calibrations.*

T. Mukaihata, M. F. Bottjer, and H. J. Tondreau (Hughes Aircraft Co.-Culver City, Calif.) described a rapid broad-band directivity-measuring technique applicable to waveguide or coaxial couplers with directivities from 10 to more than 60 db. The method minimizes measuring time, is simple in operation, and has high accuracy. A direct readout presentation of the directivity function was offered and system analysis presented. Advanced techniques for automatic plotting of directivity versus frequency were also discussed.

G. F. Engen (NBS-Boulder) presented an improved transfer instrument for the intercomparison of microwave power meters. This device eliminates the need to consider microwave impedance in such measurements. Until now, in the



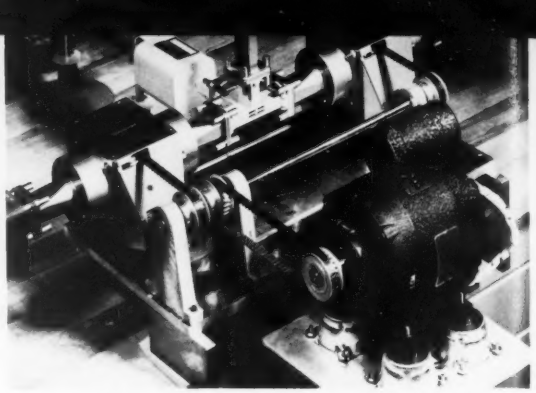
A four-arm junction which, when properly adjusted, makes possible the intercomparison or calibration of microwave power meters with little or no regard for their impedance characteristics.

intercomparison of two microwave power standards, or the calibration of a microwave power meter by means of a second or "standard" power meter, measurement of microwave impedance has played a major role. By an extension of the reflectometer concept, a four-arm junction has been devised which, when properly adjusted, allows intercomparison or calibration of power meters with little or no regard for their impedance characteristics. Of particular value in coaxial systems, the method has been found to be substantially independent of the impedance discontinuity which may be present at the input flange or connector.

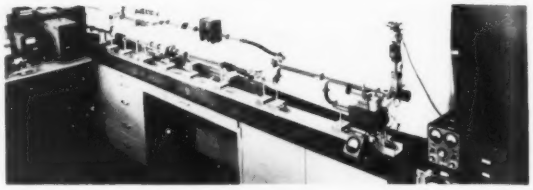
A. J. Estin, C. L. Trembath, and J. S. Wells (NBS-Boulder) offered a system for precision measurements of temperatures of microwave noise sources. In recent years, the requirement for noise-figure measurements of low noise devices has led to a need for more precise knowledge of temperatures of noise sources. The system can measure the absolute noise temperatures of a gas discharge tube in WR–90 waveguide to within 0.01 db. The comparison circuit consists of a modified Dicke radiometer. The standard noise source is a blackbody radiator at 1,000 °C. A low-loss high-temperature waveguide was developed to connect the source to the system. The results of measurement of equivalent noise temperatures of a set of 12 nonproduction argon discharge tubes, built to exacting standards of purity and precision, were presented.

R. D. Wengenroth (Wheeler Laboratories) discussed the use of a waveguide spark gap as a standard for microwave high voltages not easily determined by other means. Application is similar to that of the sphere gap employed at d-c and power frequencies but the waveguide spark gap can be between hemicylinders, cylinders, hemispheres, spheres, or posts in a rectangular waveguide section. The breakdown voltage is computed to be only a fraction of that required for the uniform waveguide. The method has been shown to be of value as a reference standard in pulsed-power tests of microwave components.

G. E. Schafer (NBS-Boulder) reported a technique for comparing phases of two microwave signals employing amplitude modulation in one channel of a two-channel system. This modulated subcarrier technique produces a null response in a two-channel system for all ratios of the amplitudes of the waves traversing the separate channels, and maintains high precision for all ratios of amplitudes. If readily available components are used, phase can be measured to one-tenth of a degree for a change of attenuation of 50 db of the component under test.



Mechanical modulator system, consisting of motor-driven rotary-vane attenuators, is a basic portion of the radiometer circuit used in temperature measurements of microwave noise sources.



Equipment used in comparing phases of two microwave signals employs amplitude modulation in one channel of a two-channel system.

R. W. Beatty, G. F. Engen, and W. J. Anson (NBS-Boulder) offered an additional use for microwave reflectometers in precise measurement of reflections and losses in waveguide joints and connectors. The reflection and loss of a waveguide joint are determined as to quantity by its VSWR and efficiency, respectively. Depending upon the stability and gain of a reflectometer with auxiliary tuners and an adjustable sliding termination, measurements of VSWR's of 1.001 and lower, and of efficiencies of 99.99 percent and higher can be obtained. The attenuations of short lengths of waveguide can be determined at the same time that efficiency is being measured.

Session V: Direct-Current and Low-Frequency Standards and Calibrations

W. G. Amey (Leeds & Northrup Co.-Philadelphia, Pa.) presided over the session on Direct-Current and Low Frequency Standards and Calibrations.

In this session, R. P. Baker (Sandia Corp.) and J. Nagy, Jr. (Daystrom, Inc.) challenged the use of conventional standard cells as references. They offered precise electrical measurements by use of zener diodes; these diodes have been investigated for use as standards in a militarized test set capable of operating many months without recalibration. Criteria for test methods and selection of diodes were established with respect to temperature coefficient, noise, and long-term stability. Improvements in these chracteristics by matching and pairing and selection of operating conditions were considered. Using a second zener reference in the test set provides a reference current for standardization of an a-c–d-c transfer device and provides a self-checking circuit which greatly increases reliability.

B. L. Dunfee (NBS-Washington) presented

the results of the first phase of a program, prompted by recent demands of science and technology, aimed at the accurate measurement of ratio and phase angle of current transformers at frequencies up to 10 kc/s. The discussion dealt with a 5/5-amp standard transformer having very small corrections, designed to operate up to 100 percent overload from 60 c/s to 10 kc/s, and a versatile test method capable of measuring ratio and phase angle to better than 5 ppm and 5 microradians. The direction of further steps in the proposed program was briefly outlined.

M. Morgan and J. Riley (Electro Measurements, Inc.) discussed techniques for calibrating a Kelvin-Varley standard divider by comparing it decade by decade with a 10-step standard divider. The standard divider, in turn, can be calibrated by precise measurement of its resistors and calculation of its linearity. The procedure for measuring each decade and the method of combining the contributions of all the decades to find the linearity deviation of a given setting were explained as a mathematical derivation. Expected accuracy, and contributions of resistor accuracy, resistor and contact stability, lead resistance, temperature variations, analytical simplification, and power dissipation were also discussed.

R. D. Cutkosky and J. Q. Shields (NBS-Washington) presented a procedure believed to be accurate to 1 part in 10^9 for measuring the voltage ratio between the two secondary windings of a three-winding transformer. Explicit formulas were developed which correct for the finite lead impedances and load admittances associated with the measuring system and yield a value for the open-circuit transformer ratio. Application of this procedure to the calibration of transformers with 10-to-1 ratios, and detailed calculations for measurements performed on a given transformer were presented.

D. L. Hillhouse and H. W. Kline (General Electric Co.-Schenectady, N.Y.) described a ratio transformer bridge for comparing inductors and capacitors with NBS certified standards to well within certified values. Comparison precisions of a few thousandths of 1 percent for 1 mh to 10 h, a few hundredths of 1 percent for 100 μh, about 0.001 percent for 0.01 to 10 μf, and better than 0.01 percent for 10 to 1,000 pf are obtained at 1,000 c/s. The effective series resistance of inductors is obtained within a few tenths of 1 percent. Factors affecting accuracy—the effects of stray and lead capacitances, inductances, and resistances—were analyzed and results presented. Integral construction allows two- or three-terminal measurements.

J. H. Park and H. N. Cones (NBS-Washington) discussed a continuously variable 0–180° phase shift standard for 400 c/s. This apparatus consists of a π-section line made up of twelve 14.6° and three 4.3° sections to provide for two sizes of coarse steps, and an RC circuit at the input to the line to provide for fine steps and continuous fine control. A method was devised for accurate adjustment of the characteristic impedance of all π-sections to the same value which is used as the termination. Under these conditions, the phase shift introduced by each π-section can be accurately computed from a measured value of inductance. As a cross-check, the phase shift of each π-section was determined by an experimental procedure depending on a 180° phase shift introduced by a toroidal transformer. The values obtained by the two independent methods agree to within 0.01°.

Session VI: High Frequency Standards and Calibrations

R. A. Soderman (General Radio Co.) presided over the sixth session, which began with a paper by D. Woods (Ministry of Aviation, London, England). Mr. Woods pointed out that to bring about an overall improvement in the accuracy of measuring electrical quantities at radiofrequency, a means first must be devised for more accurately measuring admittance. A precision dual-admittance bridge and associated standards were therefore designed for the HF and VHF bands. The bridge and a universal coaxial connector system compatible with the increased accuracy and suitable for all frequencies at which coaxial systems are normally used were described. Good matching techniques were discussed in relation to the design and utilization of extremely wide-band measuring instruments.

C. M. Allred and C. C. Cook (NBS-Boulder) discussed a new precision attenuation-calibrating system having greatly increased sensitivity, stability, and measurement range. The increases in stability and sensitivity are achieved by the use of a highly accurate piston attenuator and precision phase shifter combined into a null system. Extended attenuation measurement range is the result of a new mode-launching system which is excited by a constant current source of very high magnitude. The padding needed for correct impedance matching is minimized by using a special noninteractive combining network.

E. Uiga and W. F. White (Ballantine Laboratories) discussed how the high-frequency voltage standards developed by NBS as transfer devices between NBS standards and working instruments can be applied to such industrial problems as the calibration of electronic voltmeters. The standards consist of AT-voltmeters, thermal voltage converters, and micropotentiometers. Techniques of application were discussed with particular attention to sources of error, including human error, loading effects, voltage drop in connecting leads, stray field pickup, effect of ground currents of signal and power frequencies, transmission-line effects, response and waveform errors.

P. A. Hudson (NBS-Boulder) described a fast-reading, precision RF power transfer standard for

fixed frequencies in the range of 10 to 1,000 Mc/s, and a series of small portable wattmeters employing vacuum thermoelements. The standard consists of three directional couplers to cover the frequency range, and a series of vacuum thermoelectric detectors matched to 50 ohms at each frequency of interest. The dynamic range is 1 to 1,000 w with a resolution of 0.1 to 0.01 percent and with a stability of 0.1 percent/yr. The thermoelements are connected to the secondary line of the appropriate coupler and provide a d-c output voltage which is calibrated in terms of RF power in the coupler main line.

S. J. Raff and G. U. Sorger (Weinschel Engineering) discussed the origin of systematic error in measuring radiofrequency power by d-c or audiofrequency substitution, using balanced-bridge methods. This error source was ascribed to the very small variation of the bolometer resistance over the audiofrequency cycle. For a barretter in a typical bridge circuit, using a 10-kc/s audiofrequency, this error was shown to be about 5 percent. For thermistors, the error is generally smaller but cannot be calculated exactly because of the complex thermal behavior of the thermistor. Data were presented from which the magnitude and direction of error can be calculated as function of the bridge circuit parameter, the audiofrequency, and the bolometer time constant, whenever the latter is unique.

E. E. Aslan (FXR, Inc.) described a microwave microwatt power meter which permits full-scale measurements from 0.01 to 3 mw in six ranges over the frequency range 0.01 to 40 Gc/s. This power meter substitutes audio power for radiofrequency power. It utilizes a special thermistor mount containing two identical thermistor elements, one element positioned inside the radiofrequency field and the other element outside the radiofrequency field, but in close proximity to the other. The temperature compensation reduces the effect of temperature change to 1 percent of what it would be without compensation. The instrument is accurate to ± 1 percent at full scale on each range, exclusive of the thermistor mount. The calibration factor of a typical X-band mount is 0.98 ± 1 percent. Absolute power measurements can be made to a minimum accuracy of ± 2 percent when using a calibrated mount. Once calibrated, the power meter may be switched from range to range without recalibration.

Certification of Standards Laboratories

As a result of the greatly increased importance of precision measurement in both military and civilian technology, there has been a phenomenal growth in the number and size of standards laboratories.[1] Those who use the calibration services of these laboratories, and many of the laboratories themselves, are raising the question with increasing frequency as to whether the National Bureau of Standards certifies or otherwise "approves" other standards laboratories.

The answer to the question is that the Bureau does not rate, endorse, or place a seal of approval on any other laboratory. The Organic Act which defines the functions and activities of the Bureau does not give it any authority either directly or by implication to pass upon the qualifications of others who render standardization services. The Organic Act was wisely framed in this regard because the Bureau can best exercise its responsibility for providing standards of measurement for the Nation when it acts in the capacity of a scientific agency rather than as a regulatory agency. Competence in precision measurement that the Bureau wishes to cultivate on the part of other standards laboratories can best be achieved through cooperation rather than by compulsion through the enforcement of minimum requirements.

The Bureau does strive, therefore, by all means at its disposal to promote the competence and effectiveness of other laboratories.[2] In addition to calibrating and certifying standards, the Bureau often provides information which may be helpful in the design and planning of new laboratories, the selection of equipment, and the development of procedures, and is concerned daily with numerous specific problems of measurement brought to it by other laboratories.

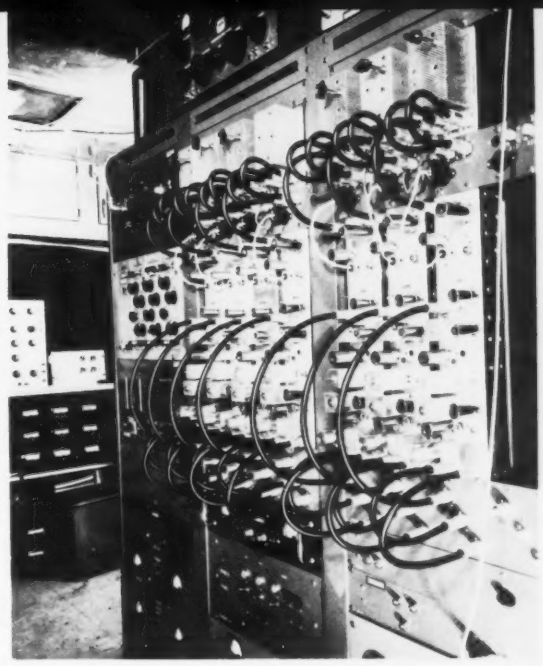
It is recognized by all that a laboratory which offers standardization services to the Government or the public is accepting an important responsibility and, hence, should meet high standards for the professional competence of its staff, the adequacy of its facilities and equipment, and the reliability and accuracy of its work.

Training, experience, publications, participation in technical society activities, recommendations from other users of the laboratory's services, etc., are of assistance in judging the competence of the professional staff. The adequacy of the facilities and equipment may be judged in part by the available certificates or reports of calibration for their reference standards. In addition, the performance of a laboratory can be checked against that of other laboratories working in the same measurement areas by means of roundrobin or other interlaboratory test arrangements.

In short, the selection of a laboratory for calibration services can best be made in much the same manner as the selection of a firm to render other professional services.

[1] Standards and calibration activities in rapid growth, *NBS Tech. News Bull.* **43**, *221 (1959)*.

[2] Assistance to other standards laboratories, *NBS Tech. News Bull.* **43**, *21 (1959)*.



Electronic rapid scanning device, contained in a trailer on Table Mesa beside the Yagi antenna (see cover), swings a 5.8° beam in azimuth through the 42° sector 20 times a second. An oscilloscope is synchronized to the incoming signal and permits direct viewing and photographing. The device is unique in that it operates by purely electronic control of phasing and involves no mechanical apparatus such as that used for the sweep of radar antennas.

High-Resolution Scanning Antenna

An antenna developed by the Bureau promises to provide science with a new tool for experimental studies of the ionosphere. Without benefit of electric or mechanical moving parts, it scans a 42°azimuthal arc and can determine immediately the direction of radio signals received from a forward-scatter transmission.

In this type of VHF radio propagation, radio energy is scattered from cloudlike concentrations of electrons in the lower ionosphere and may arrive at the receiver site from any number of directions. The new development can pinpoint instantly the direction from which the scattered signal arrives and could prove invaluable in tracing "best paths" for forward-scatter communication. It can be adapted for use in the observation of a number of other ionospheric phenomena.

At Table Mesa, a field station of the NBS Boulder Laboratories, H. V. Cottony and Alvin C. Wilson, of the Antenna Research Section, have erected a row of seven 5-element Yagi antennas, directed along the Great Circle Path to the NBS Long Branch field station transmitter in Havana, Ill.—800 miles from Boulder. The number of elements in the array is now being increased to 25 to permit a beam width of only 1.5°.

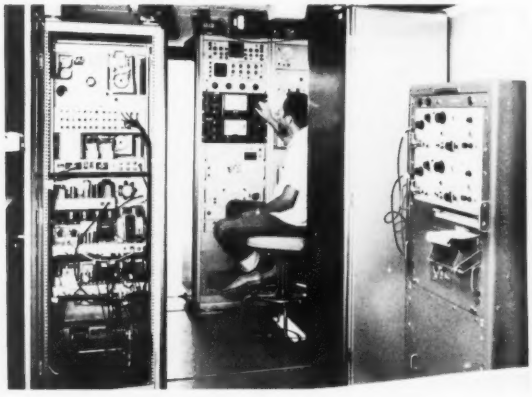
Radio signals beamed from the Havana station at a frequency of 41 Mc into the ionosphere are received at Table Mesa, but, heretofore, the direction from which the signal was reflected by the electron "clouds" has remained unknown.

The electronic rapid scanning device, developed for use with the moderately directive Yagi antennas, swings a 5.8° beam in azimuth through the 42° sector 20 times a second. An oscilloscope synchronized to the incoming signal permits direct viewing or photographing. The device is novel in that it operates by purely electronic control of phasing and involves no mechanical apparatus such as that used for the sweep of radar antennas.

The ionospheric forward-scatter mode of radio propagation has distinct advantages in that it is resistant to the polar blackouts which so often cause complete fading in other modes of short-wave propagation. Up to the present there has been no method for determining the path of the received signal, but now the direction of arrival of an ionospheric scatter signal can be seen—and followed as the signal path shifts.

Besides providing a method for study of long-distance ionospheric forward-scatter communication phenomena, the antenna will be a valuable tool for other experimental studies. Bearings of ionized meteor trails may be obtained instantly. The principle is applicable to a design of an antenna array for riometers (devices that listen to extraterrestrial, or cosmic, noise which partially penetrates the ionosphere). It could be used as a small-space, multidirection antenna for receiving and—with design changes—for transmitting. It is considered to have a number of possible uses in many of the research programs now probing toward outer space.

Mobile Electronic Laboratory



One of two mobile electronic laboratories developed by the Bureau's Central Radio Propagation Laboratories for conducting radio propagation studies in isolated areas. Such experiments frequently must be conducted away from manmade interference, near a particular existing installation, or over unique terrain conditions. Equipment in the trailers is designed to study time variations in refractivity at one or more points along a radio propagation path and the corresponding variations in the phase of arrival of a microwave signal transmitted over the path. Initially developed for a study at Cape Canaveral, the 35-ft trailers contain—in addition to their electronic instrumentation—office, sleeping, and kitchen facilities for two men.

Announcing the Third National Symposium on

Temperature—Its Measurement and Control in Science and Industry

A NATIONAL symposium on *Temperature—Its Measurement and Control in Science and Industry* will be held in Columbus, Ohio, March 27 to 31, 1961, jointly sponsored by the American Institute of Physics, the Instrument Society of America, and the National Bureau of Standards, with other societies and governmental agencies cooperating.

This will be the first conference of this breadth and scope since the New York conference on the same subject in 1939. The symposium will be aimed at the fundamentals of temperature measurement to complement the material in the 1939 volume and will provide an authoritative blending of papers on the meaning of the temperature concept as well as analytical theory, with appropriate emphasis on instrumentation and the engineering aspects; e.g., thermocouples and radiation pyrometry in full range of temperature. Interests from cryogenics to ultra-high plasma temperature will also be covered.

The symposium is being designed to present broad fundamental coverage of the subject for scientific and engineering personnel who are concerned with temperature problems. A reference book based on symposia material will be published.

General chairman of the symposium is W. A. Wildhack, Special Assistant to the Director of the National Bureau of Standards. Dr. Elmer Hutchisson, Director of the American Institute of Physics, is vice chairman, and Mr. C. L. Roberson, manager of the Mechanical Research Laboratory of the Owens-Corning Fiberglas Corp., is secretary. Dr. C. M. Herzfeld, Chief, Heat Division of the Bureau, is chairman of the Program Committee.

Those interested in contributing to the program should contact Dr. Herzfeld at the National Bureau of Standards, Washington 25, D.C., as soon as possible for details.

U.S.-Japanese Intercomparisons of Microwave Power Standards

THE BUREAU has completed four additional intercomparisons of microwave power standards with Japan in accordance with the recommendations of the International Scientific Radio Union. These intercomparisons, made by the Bureau's Radio Standards Laboratory at Boulder, Colo., show much better agreement than an earlier one made in December 1957,[1] and closer agreement than an intercomparison made with Britain in July 1958. The discrepancy in the earlier measurement was attributed to the long time interval that had elapsed between the measurements in Japan and the United States, respectively.

The Japanese power standards are in the form of bolometer (baretter) mounts. The mount submitted by Japan in 1957 was compared with a similar NBS mount by observing the power indicated by each when alternately connected to a signal generator of constant output amplitude. The NBS mount is calibrated by a refined X-band microcalorimeter.

A second mount, provided by Japan in the fall of 1959, showed the following intercomparison results:

Measurement in Japan

Effective efficiency (by microcalorimetric techniques)	98.38	$\begin{cases}+0.6\% \\ -0.3\%\end{cases}$
Efficiency (by impedence techniques)	95.2	±2%
(second determination)	95.5	±2%

Measurement in United States

Effective efficiency (by microcalorimetric techniques)	99.1	±0.7%
Efficiency (by impedance techniques)	98.5	±0.7%
(second determination)	98.7	±0.7%

In April 1960 a third bolometer mount was provided by Japan and compared with the following results:

Measurement in Japan

Effective efficiency	98.73	$\begin{cases}+0.6\% \\ -0.3\%\end{cases}$
Efficiency	95.8	±2%
(second determination)	97.1	±2%

Measurement in United States

Effective efficiency	98.85	±0.7%
Efficiency	98.8	±0.7%
(second determination)	98.7	±0.7%

More recently a pair of bolometer mounts which had been prepared by the Bureau's Boulder Laboratories were sent to Japan for measurement with the following result:

Measurement in United States

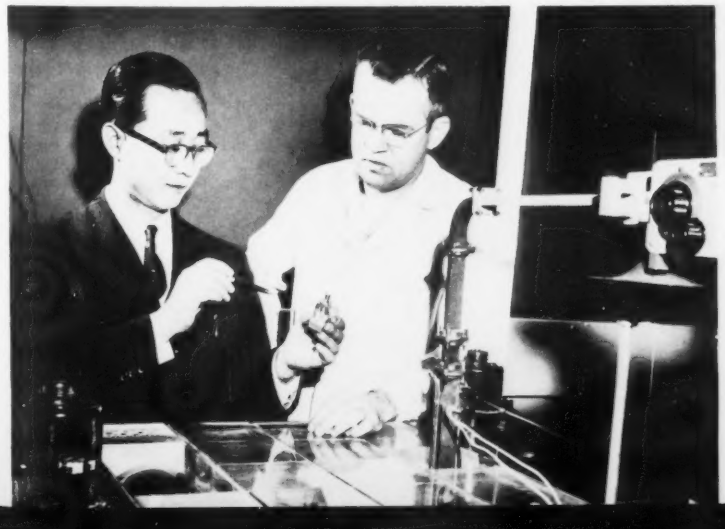
Effective efficiency (Mount A)	98.12	±0.2%
Effective efficiency (Mount B)	98.47	±0.2%

Measurement in Japan

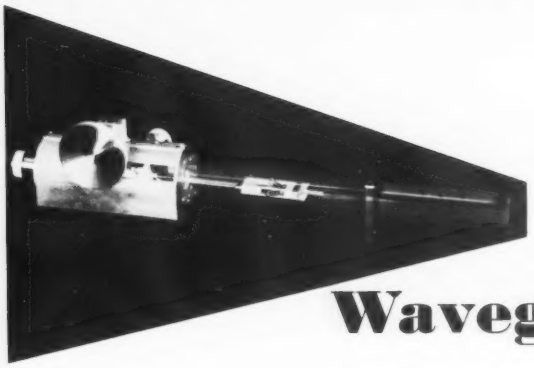
Effective efficiency (Mount A)	98.34	$\begin{cases}+0.6\% \\ -0.3\%\end{cases}$
Effective efficiency (Mount B)	98.74	$\begin{cases}+0.6\% \\ -0.3\%\end{cases}$

The agreement between the calorimetric determinations, particularly in the latter intercomparison, is considered exceptionally good, and is well within the estimated limits of error for the individual measurements.

[1] *See* Recent international comparisons of microwave power standards, *NBS Tech. News Bull.* **43**, *155 (August 1959)*.



Preparations are made for the intercomparison of Japanese and American standards of microwave power.



Adjustable Waveguide Termination

Adjustable sliding termination for rectangular waveguide developed at the Bureau has two moving parts: a short-circuiting plunger which slides inside the waveguide, and a rectangular resistance vane attached to a dielectric rod. Double exposure shows the plunger and vane positioned inside the waveguide.

AN ADJUSTABLE sliding waveguide termination that reduces reflections to a minimum in microwave measurements has been developed by the Bureau. Devised by R. W. Beatty of the Radio Standards Laboratory at Boulder, Colo., the instrument [1] has a minimum VSWR (voltage standing wave ratio) of less than 1.0002, or a return loss greater than 80 db.

The instrument is more stable, and of simpler and more durable construction than previous devices of this type. It provides a wide range of reflection coefficients and can easily be scaled to different waveguide sizes. Moreover, it is easily adjusted because of the independent variation and locking of three separate mechanical motions.

The instrument is being used by the Bureau to measure conveniently and accurately the directivity of directional couplers.[2] Reflection from the adjustable sliding termination is varied in magnitude and phase until it cancels the signal component—which exists because of finite directivity—coupled out of the sidearm of the directional coupler. The termination is adjusted until the output is maximum, whereupon the signals add. This maximum is compared to the sidearm output when the adjustable termination is replaced by a short circuit. The ratio of the two signals is half the directivity ratio of the coupler, provided that the system has first been tuned [3] so that the reflection coefficient "looking in" to the coupler output waveguide is zero. If this is not done, the reflection interactions would cause decreased accuracy.

Another useful application of the adjustable sliding termination is in the measurement of the reflections from waveguide discontinuities, flanges, steps in the height of rectangular waveguide, and obstacles in the waveguide. With this termination, no ambiguity needs to be resolved and nulling adjustments are both extremely sensitive and easy to make. The procedure is similar to that for the directivity measurement except that a directional coupler-tuner combination (previously adjusted for infinite directivity) is used to indicate the total reflection, which consists of the sum of the fixed reflection from the discontinuity and the phasable reflection from the adjustable sliding termination.

The auxiliary tuners of a single directional coupler reflectometer can conveniently be adjusted for infinite directivity and match back with the sliding termination. As this technique usually shortens the adjustment procedure, it is used in the NBS Electronic Calibration Center in calibrating microwave reflection standards.

Additional uses of the adjustible sliding termination have been suggested for various measurement techniques. For example, using this principle, an adjustable VSWR standard [4] can be constructed and then calibrated along with other standards through suitable comparison techniques. Errors in a comparison technique are naturally minimized if the two compared loads have essentially the same impedance.

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[1] *For further technical information see United States Patent No. 2,922,963 of Jan. 26, 1960,* An adjustable sliding waveguide termination. *Also see* An adjustable sliding termination for rectangular waveguide, *by Robert W. Beatty, IRE Trans. on Microwave Theory and Techniques (July 1957).*

[2] A method for measuring the directivity of directional couplers, *by G. E. Schafer and R. W. Beatty, IRE Trans. on Microwave Theory and Techniques (Oct. 1958).*

[3] Microwave reflectometer techniques, *by G. F. Engen and R. W. Beatty, IRE Trans. on Microwave Theory and Techniques (July 1959).*

[4] Recently developed microwave impedance standards and methods of measurement, *by R. W. Beatty and D. M. Karns, IRE Trans. on Instr. (Dec. 1958).*

A Proposed Analog-Digital Differential Analyzer

THE BUREAU has been investigating a proposed analog-digital differential analyzer[1] that combines the analog advantages of high speed and continuous representation of variables with the digital capability for high precision and dynamic range. It represents dependent variables by two quantities, a digital number representing the more significant part, and an analog electrical voltage representing the less significant part.

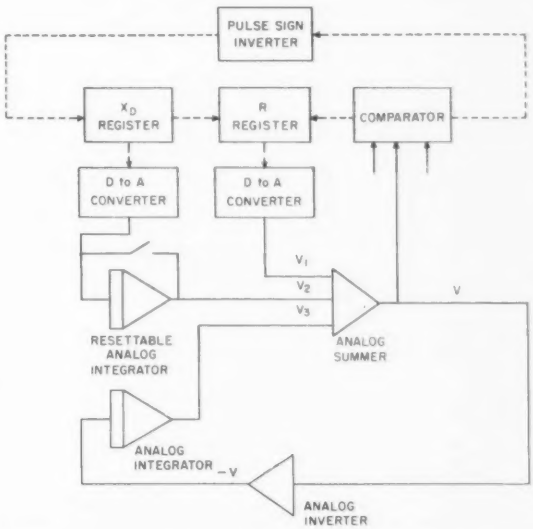
Developed by H. K. Skramstad of the data processing systems laboratory, the proposed analyzer appears to be naturally applicable in simulating the dynamic problems in missile or aircraft design studies. The addition of short digital registers and other digital components to an analog computer provides the increased precision required for solving such problems, while retaining the speed of the analog computer.

The electronic analog computer, although useful in solving dynamic problems described by differential equations, suffers from limitations of accuracy and dynamic range. The digital differential analyzer can provide any required degree of accuracy or dynamic range, but it can be relatively slow in operation and subject to possible instability of solution resulting from numerical representation of the variables and the use of finite different calculus in integration. Using both analog and digital techniques in a single analyzer makes it possible to combine the advantages of each for solving problems rapidly and with the desired level of precision.

So far, an integrator and a multiplier have been designed. In general, they consist of one or more of the following units: an input digital register, a register for accumulating digital results, a digital-to-analog converter, a conventional analog integrator, a resettable analog integrator, an analog summer, and a comparator. These basic units can be constructed from electronic digital and analog circuits in present common usage. Analog-to-digital converters are not required for this system.

The overall analyzer is designed so that the time period (Δt) during which the numbers in the digital registers do not change is made as small as possible, consistent with component limitations, in order to permit the maximum number of such periods. The greatest speed and precision are realized, of course, with the smallest Δt. However, Δt must be long enough not only to permit full-scale excursions of the various analog voltages, but also to fit within the bandwidth limitations of the operational amplifiers. Improvement in the characteristics of these units will help reduce Δt. Even with present components, it is estimated that the precision in solving problems can be increased by a factor of 10 to 100 over conventional analog methods.

Under the sponsorship of the Bureau of Naval Weapons, work has recently begun on the construction of breadboard models to evaluate the system. These circuits will contain two integrator and two multiplier units, each capable of receiving input voltages from other units. Digital registers and digital-to-analog converters will be constructed from transistorized digital packages,[2] and the analog components from commercially available wide-band operational amplifiers. These units will have 8-bit plus sign input and accumulating registers, and an analog reference voltage of 10 v. They will operate with a Δt of 1 msec or less.



Block diagram of integrator to solve $dx/dt = -x$ shows how the proposed analog-digital system could be used to solve a simple differential equation.

[1] *For further technical information, see* A combined analog-digital differential analyzer, *by H. K. Skramstad, Proc. Eastern Joint Computer Conference (1959).*

[2] Packaged switching circuits, *NBS Tech. News Bul.* **43**, 184 (October 1959).

Publications of the National Bureau of Standards

Periodicals

Technical News Bulletin, Volume **44**, No. 8, August 1960. 15 cents. Annual subscription: $1.50, 75 cents additional for foreign mailing. Available on a 1-, 2-, or 3-year subscription basis.

Basic Radio Propagation Predictions for November 1960. Three months in advance. CRPL–D192, issued August 1960. 15 cents. Annual subscription $1.50, 50 cents additional for foreign mailing. Available on a 1-, 2-, or 3-year subscription basis.

Journal of Research of the National Bureau of Standards

Section A. Physics and Chemistry. Issued six times a year.

Annual subscription: Domestic, $4; foreign $4.75.

Section B. Mathematics and Mathematical Physics. Issued quarterly.

Annual subscription: Domestic, $2.25; foreign, $2.75.

Section C. Engineering and Instrumentation. Issued quarterly.

Annual subscription: Domestic, $2.25; foreign, $2.75.

Section D. Radio Propagation. Issued six times a year.

Annual subscription: Domestic, $4; foreign, $4.75.

Section B. Mathematics and Mathematical Physics, Volume **64B**, No. 3, July–September 1960.

Electric polarizability of a short right circular conducting cylinder, T. T. Taylor.

Distribution of quantiles in samples from a bivariate population. M. M. Siddiqui.

Split Runge-Kutta method for simultaneous equations, J. R. Rice.

A reduction formula for partitioned matrices, E. V. Haynsworth.

Selected bibliography of statistical literature, 1930 to 1957: III. Limit theorems, L. S. Deming.

Section C. Engineering and Instrumentation, Volume **64C**, No. 3, July-September 1960.

A new method of measuring gage blocks, J. B. Saunders.

Gage blocks of superior stability: initial developments in materials and measurement, M. R. Meyerson, T. R. Young, and W. R. Ney.

Variation of resolving power and type of test pattern, F. E. Washer and W. P. Tayman.

A multiple isolated-input network with common output, C. M. Allred and C. C. Cook.

Phase angle master standard for 400 cycles per second, J. H. Park and H. N. Cones.

Disturbances due to the motion of a cylinder in a two-layer liquid system, L. H. Carpenter and G. H. Keulegan.

Nonperiodicals

Measurement of neutron flux and spectra for physical and biological applications. NBS Handb. 72 (1960), 35 cents.

New description of thorium spectra, R. Zalubas. NBS Mono. 17 (1960) 65 cents.

Technical Notes

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